MSU HiTEC Program

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Mechanical & Industrial Engineering

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MSU HiTEC

High Temperature Electrochemistry

- Solid Oxide Fuel Cell Development
- Solid Oxide Electrolyzer Development
- Solid Oxide H_2 Separation Membranes
- Power Electronics

$T_{operation}$ ~ 500 – 1000°C

SOFC Advantage

Higher Efficiencies (with non-noble metal catalysts)

•Greater than 50% efficiency potential

Reformed Hydrocarbon Based Fuels

•Syngas (H_2 + CO)

•Can be used directly in SOFC systems

Promise of Sulfur Tolerance

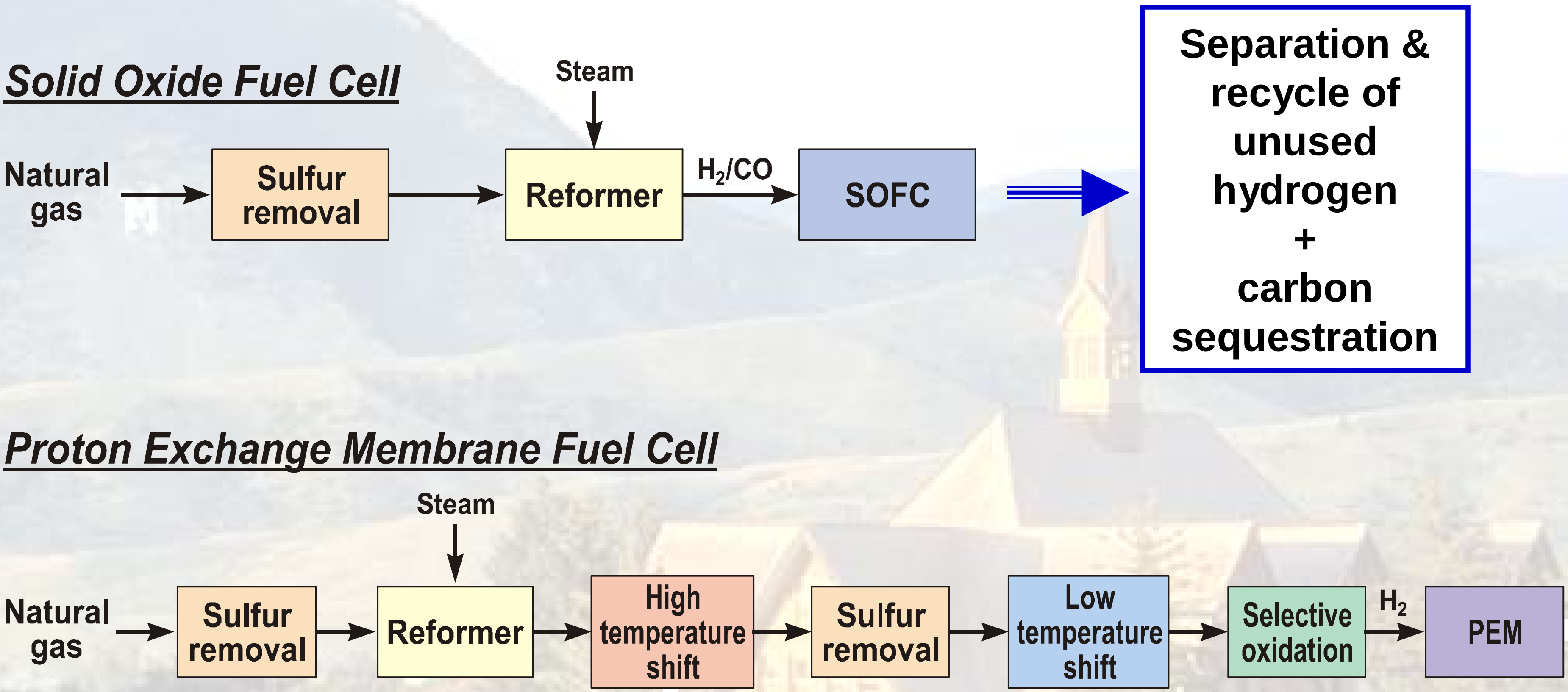
•Jet Fuel (JP-5, JP-8, Jet A) 3000ppm limit, ~400ppm avg.

•Gasoline 350ppm limit, ~200ppm avg.

•Diesel 500ppm limit, ~325ppm avg.

•Propane, Butane, Methane, ~200ppm avg.

PEM vs SOFC Reformation

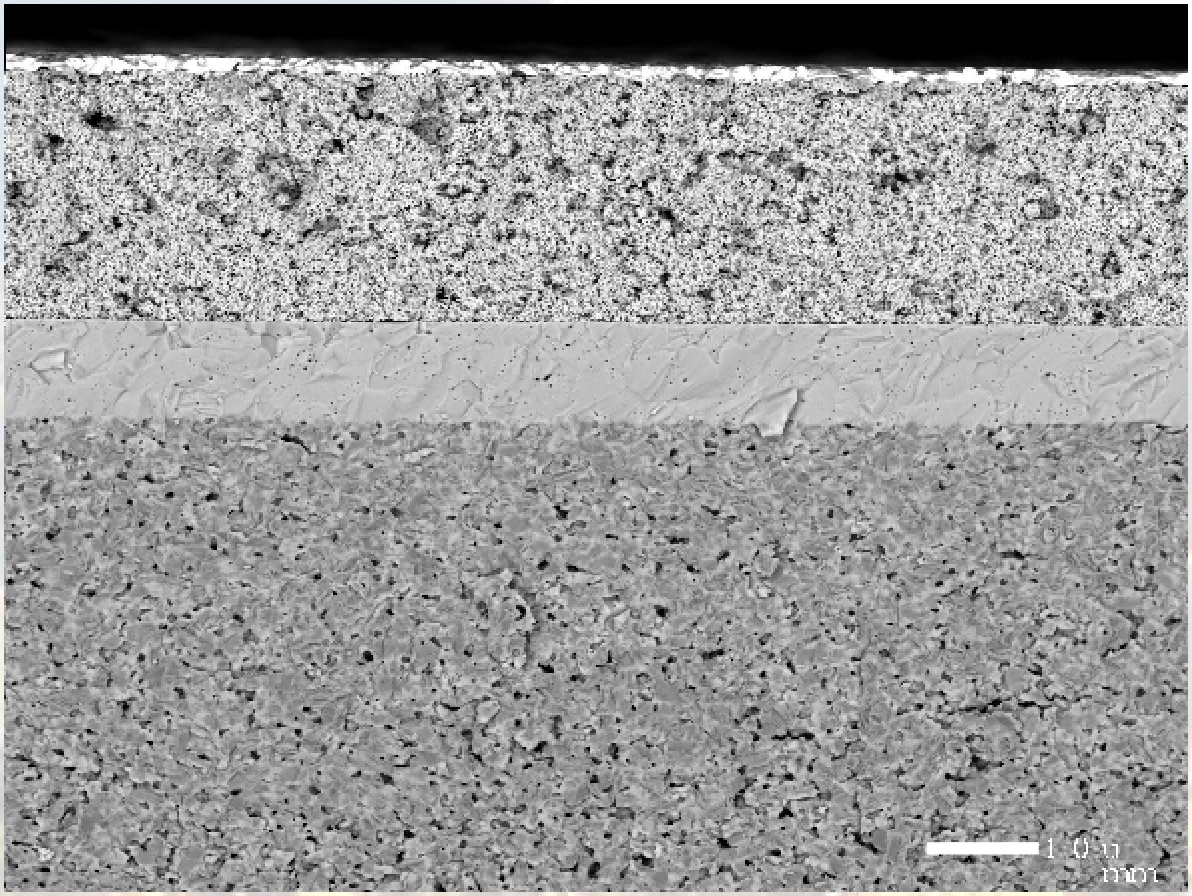


Overview

- **SOFC Ceramic Processing, Fabrication, & Performance Testing**
- **Metallic Interconnect Coatings** (Arcomac Surface Coatings)
- **Characterization of Internal Interfaces & Surfaces** (x-ray, RBS, electron microscopy)
- **SOFC Transient Response Modeling**
- **Hydrogen Separation Membranes** (Coal Gasification)

Solid Oxide Fuel Cell

State of the Art SOFC



Current Collector

LSM / YSZ Composite

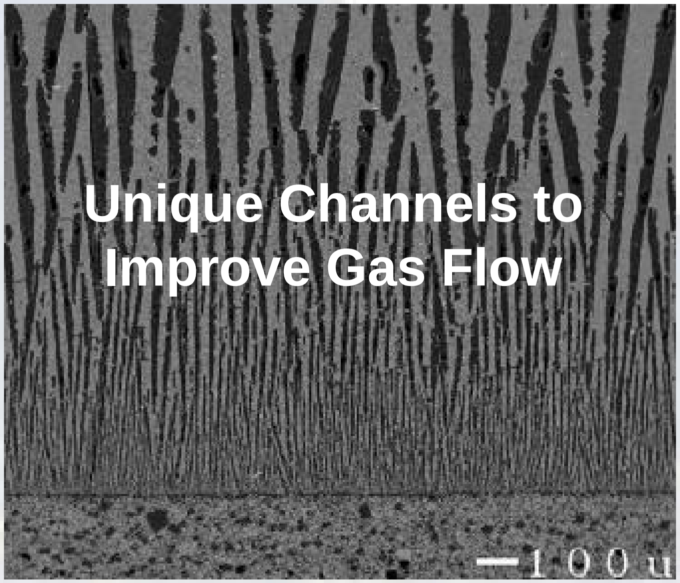
YSZ

Ni / YSZ Cermet

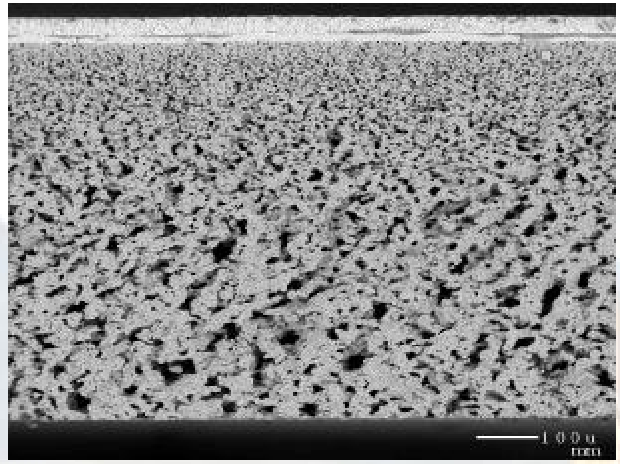
SOFC Fabrication Capabilities

(Anode Supported Cell with 10 micron electrolyte)

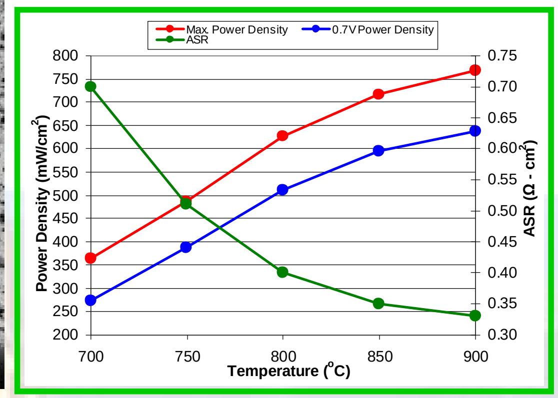
Microstructural Engineering

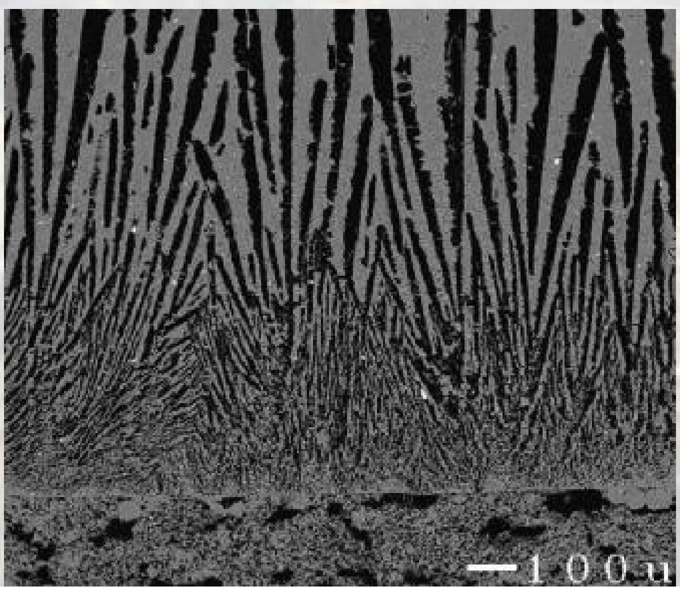


Unique Channels to Improve Gas Flow



NASA Patented Process

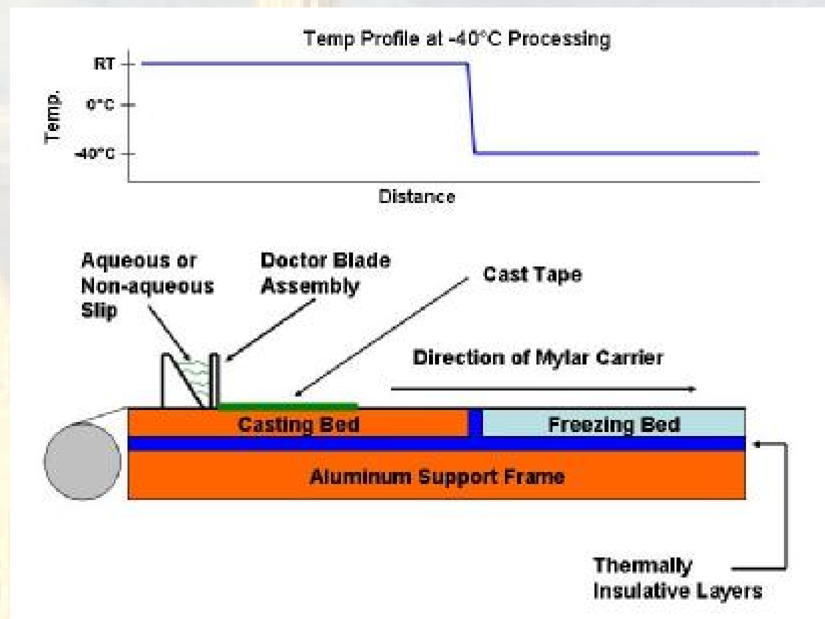




Improve FU

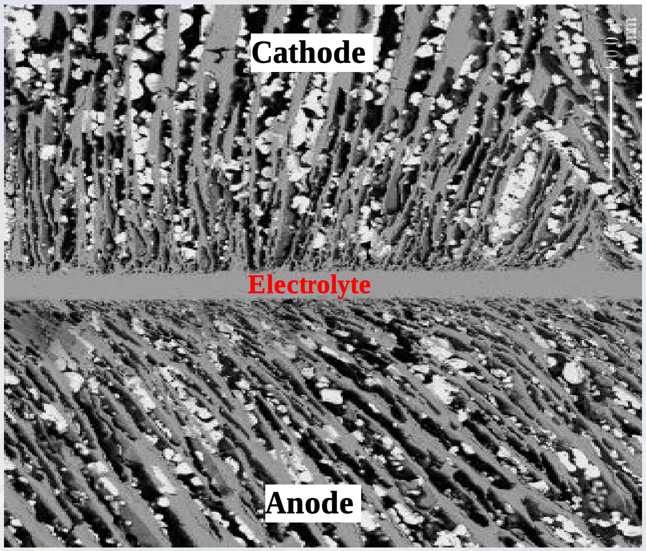
Decrease Cost

Improve Strength

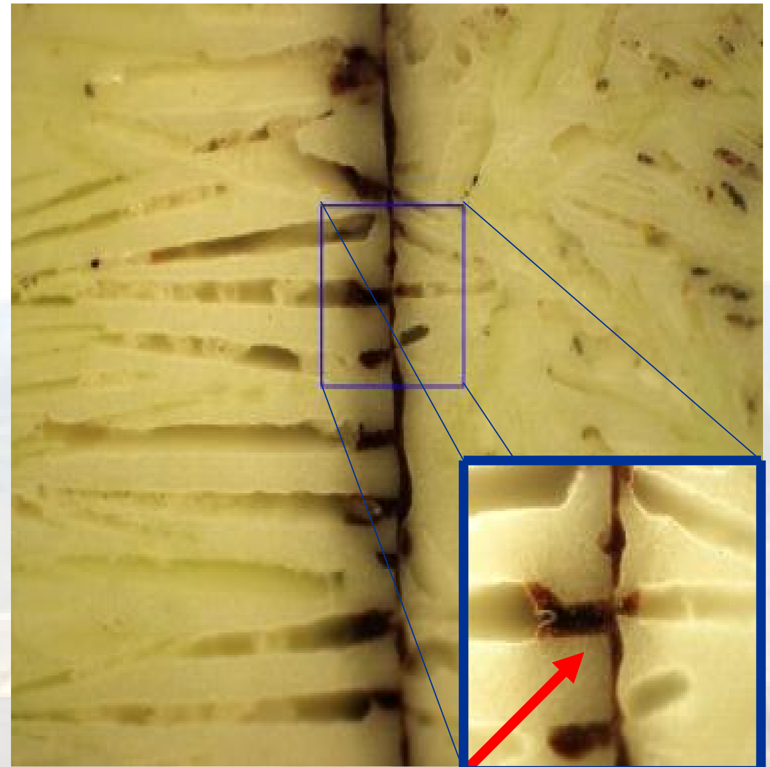


Based on current industrial processes

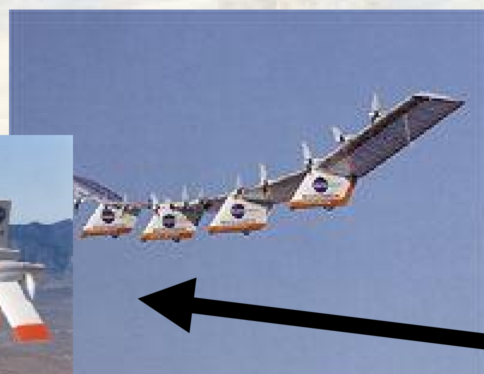
High Power Density SOFC's



New Concept SOFC Designs



Textured Interfaces



Reduce overall mass and volume of system to achieve high specific power densities in excess of 1.0 kW/kg

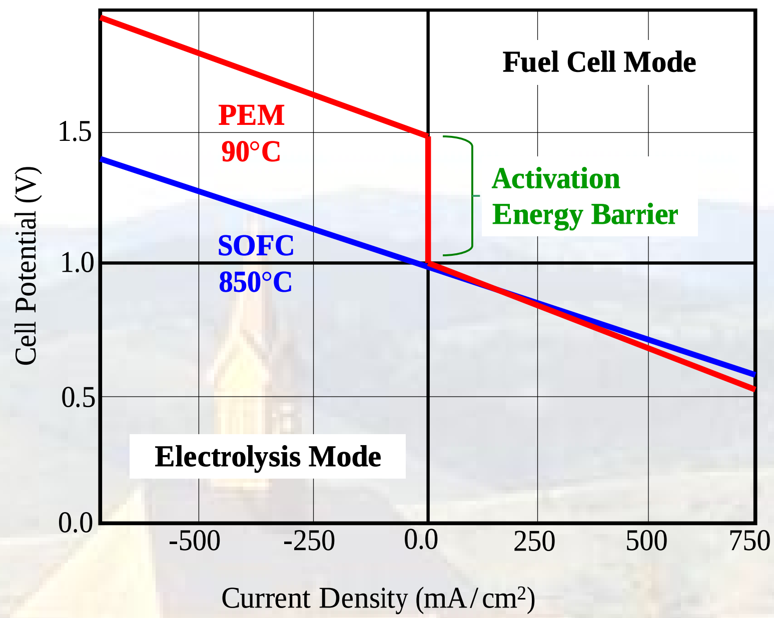
These technologies are early adopters

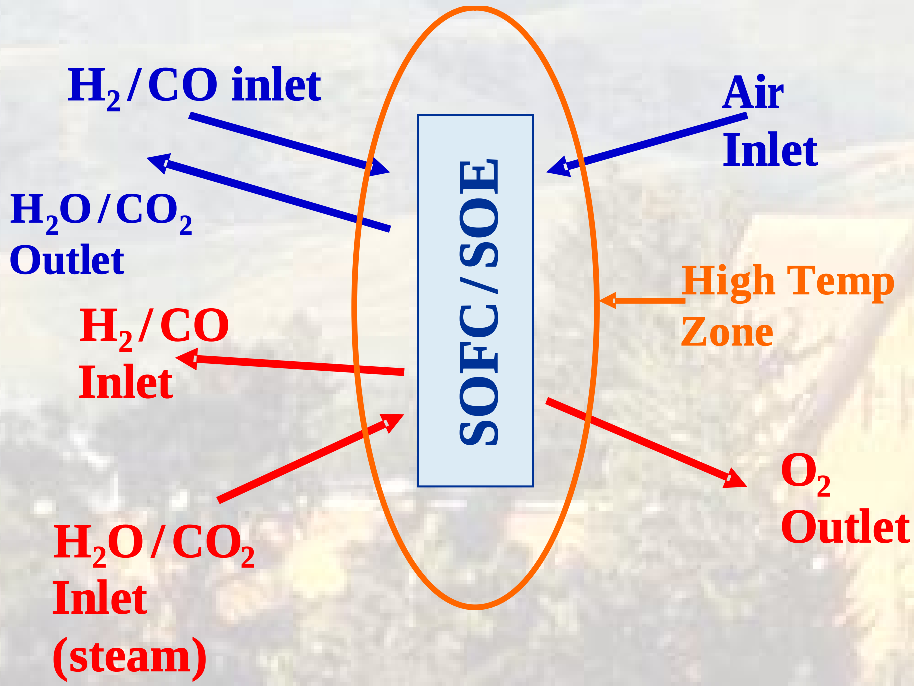
Unitized Regenerative SOFC's

Distilled Water = Fuel Source

Energy + H_2O è H_2 + O_2

H_2 + O_2 è H_2O + energy





Power Mode

Electrolyzer Mode

Sulfur Tolerance

Traditional nickel based anode systems can be sensitive to 1 – 10ppm H_2S

New modified nickel and all ceramic systems can be tolerant up to 500ppm H_2S

- **This exceed sulfur limits in some fuel sources**

With analytical characterization techniques, identify mechanisms of sulfur degradation

Further develop new anodes that are resistant to sulfur attack and compatible with existing fuel cell materials and architectures

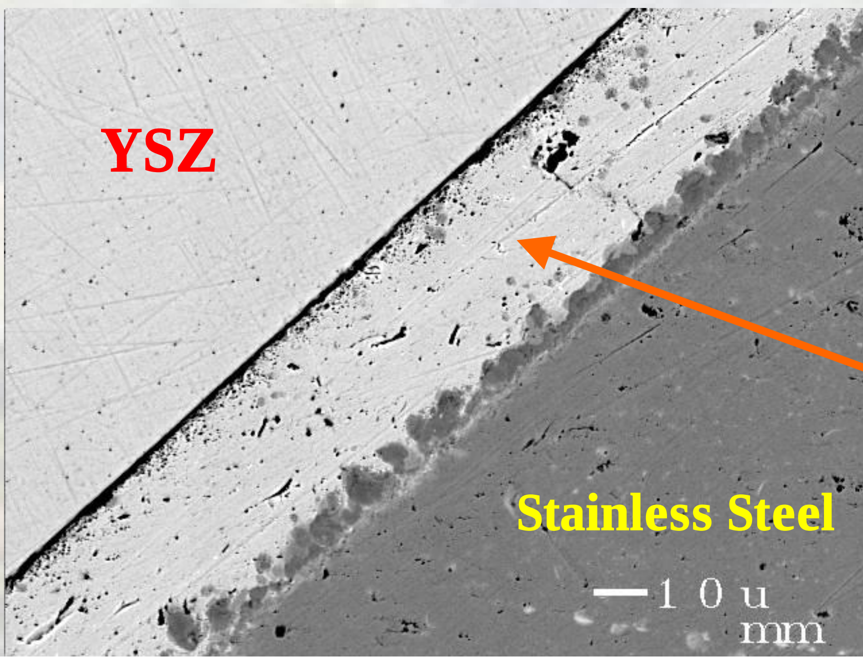
SOFC Sealing

High Temperature Brazing

•Metals have high ductility, high thermal conductivity, and self healing behavior that is ideal for SOFC sealing
•Challenges: electronic conductivity, bonding, high thermal expansion

Single most critical challenge in the commercialization of SOFC stacks

Glass Seals have been traditionally studied

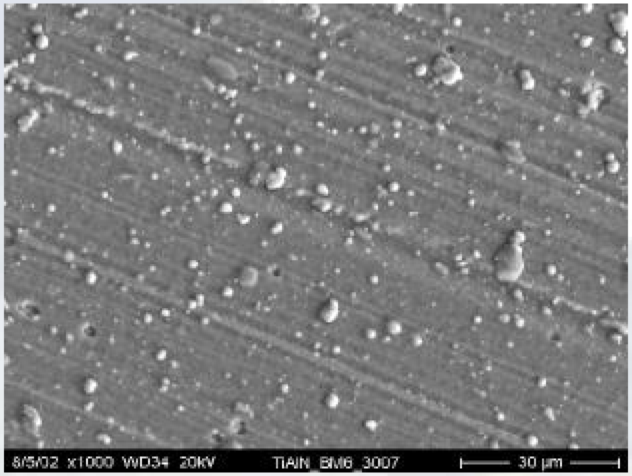


Use oxide forming additives to yield electrically resistive scales

Non-conductive chemically bound braze joint

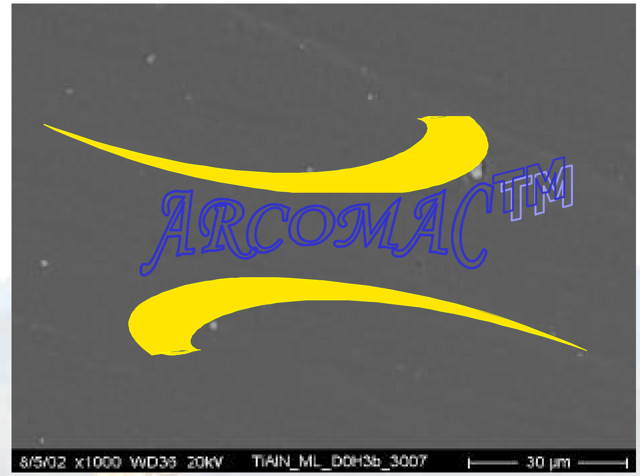
Surface Coatings

TiAlN



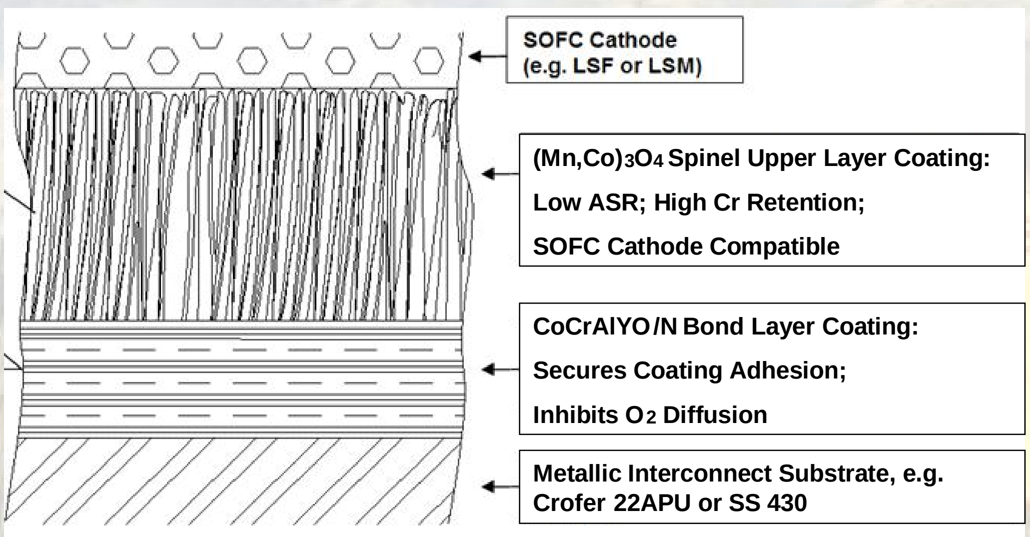
CONVENTIONAL (KENNAMETAL)

ARCOMAC^{TM}



Filtered Arc Deposition

Hybrid SOFC Interconnect Coatings



ANALYSIS

Coating adhesion

Comp. and Morphology

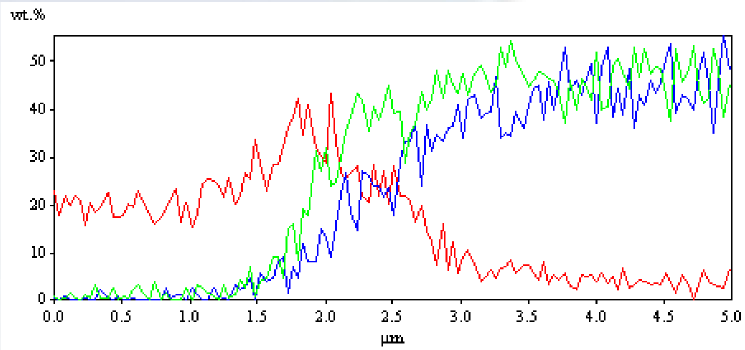
Electrical Conductivity

Oxidation Stability

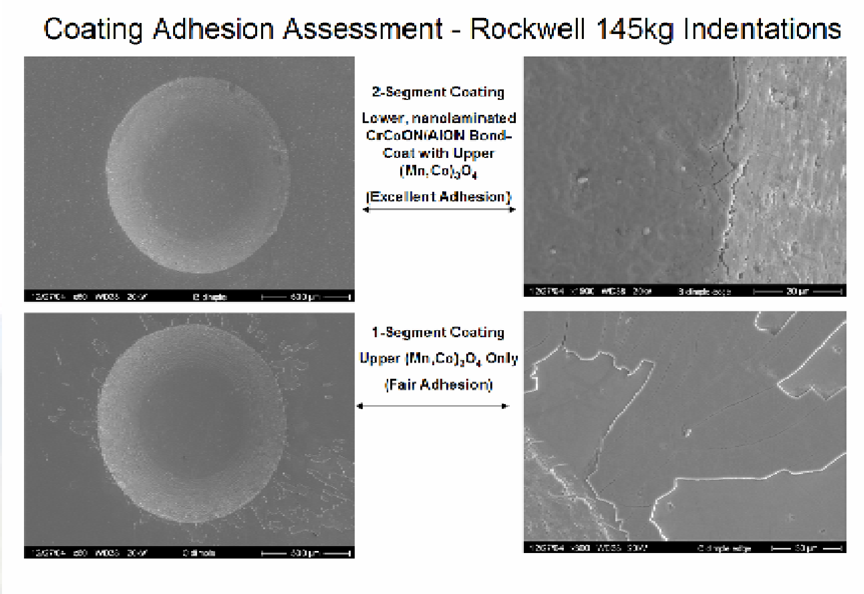
Cr Volatility (LBNL)

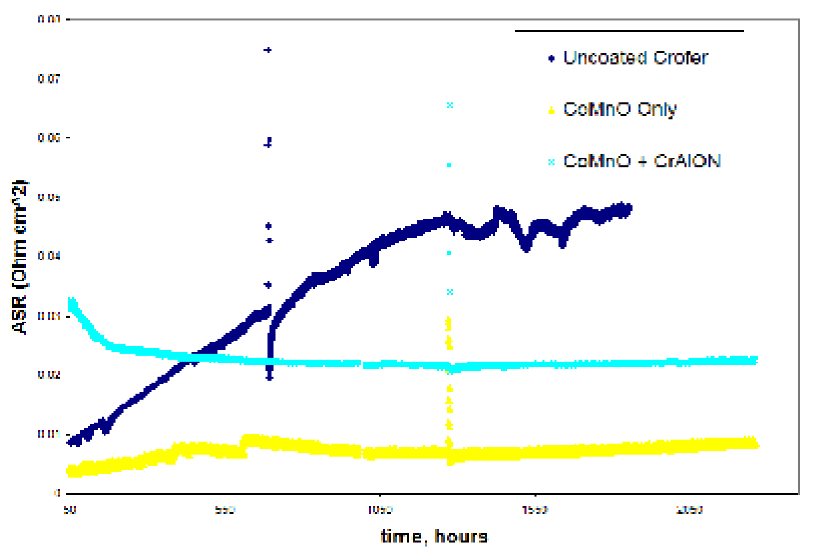
Interconnect Coatings

Linescans of Cr, Mn, and Co



Cross Section SEM



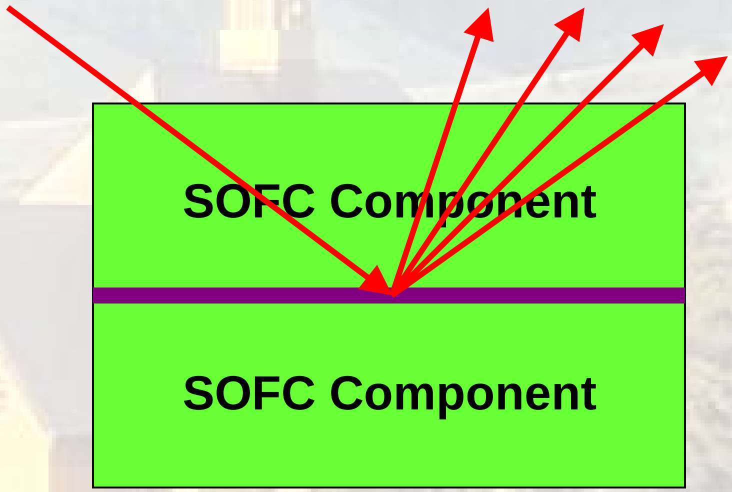


Electrical Conductivity Performance

MSU Materials X-ray Characterization Facility at the National Synchrotron Light Source

Analysis Capability
- **XAS**
- **XAFS**
- **XRS**

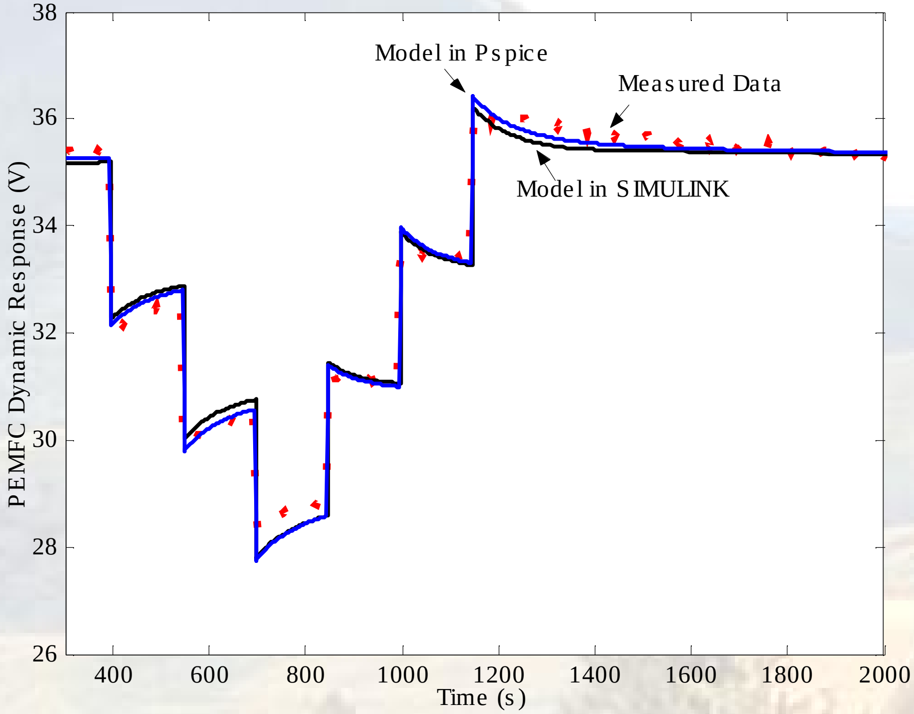
U_4B - Soft X-rays
X_{23} - Hard X-rays **ü ü ü**



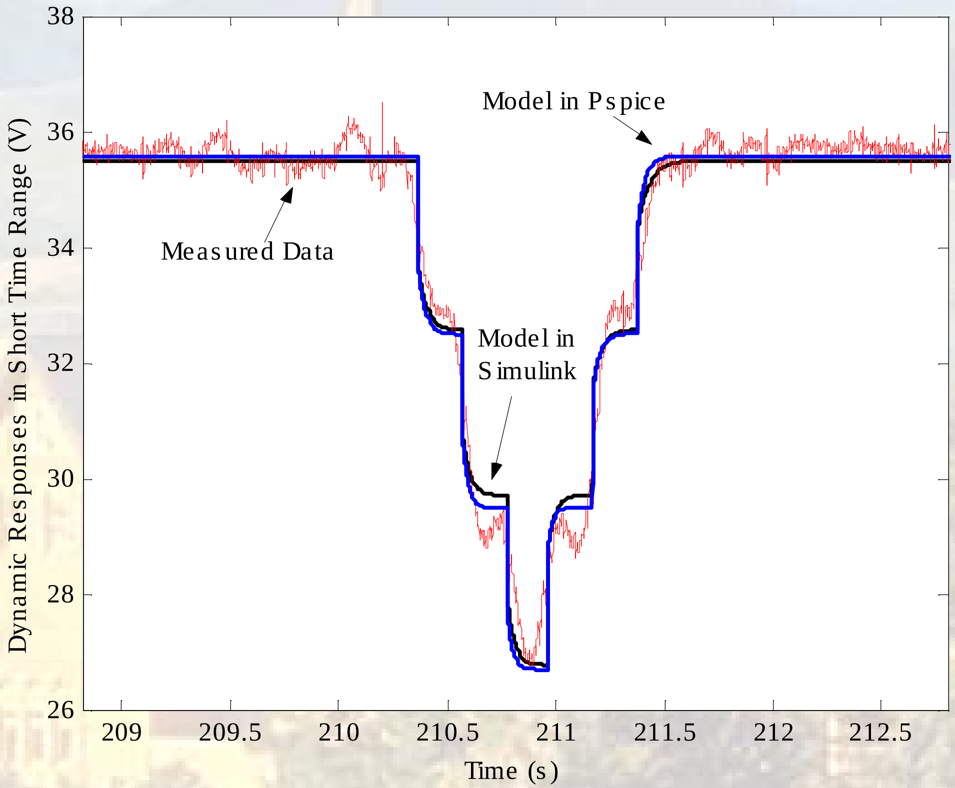
Characterize Buried Interfaces Non-destructively (identify degradation mechanisms & incompatibilities)

Power Electronics

Transient responses of the models in long time range.



Electrical Response Modeling



Transient responses of the models in short time range.

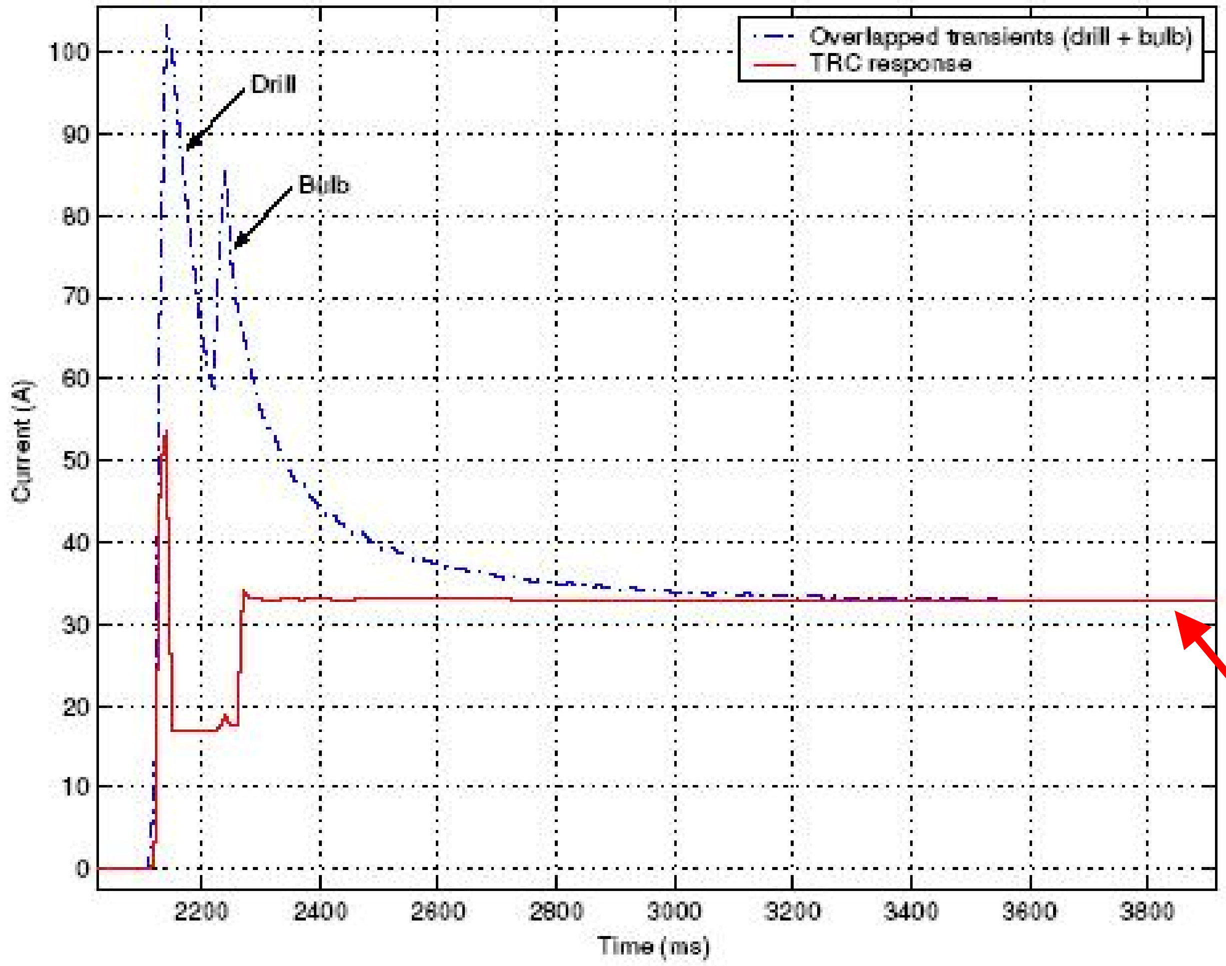
PEM Dynamic *Response*

ð Apply to SOFC's

Transient Recognition Control

Advanced multisource control

Overlapping events

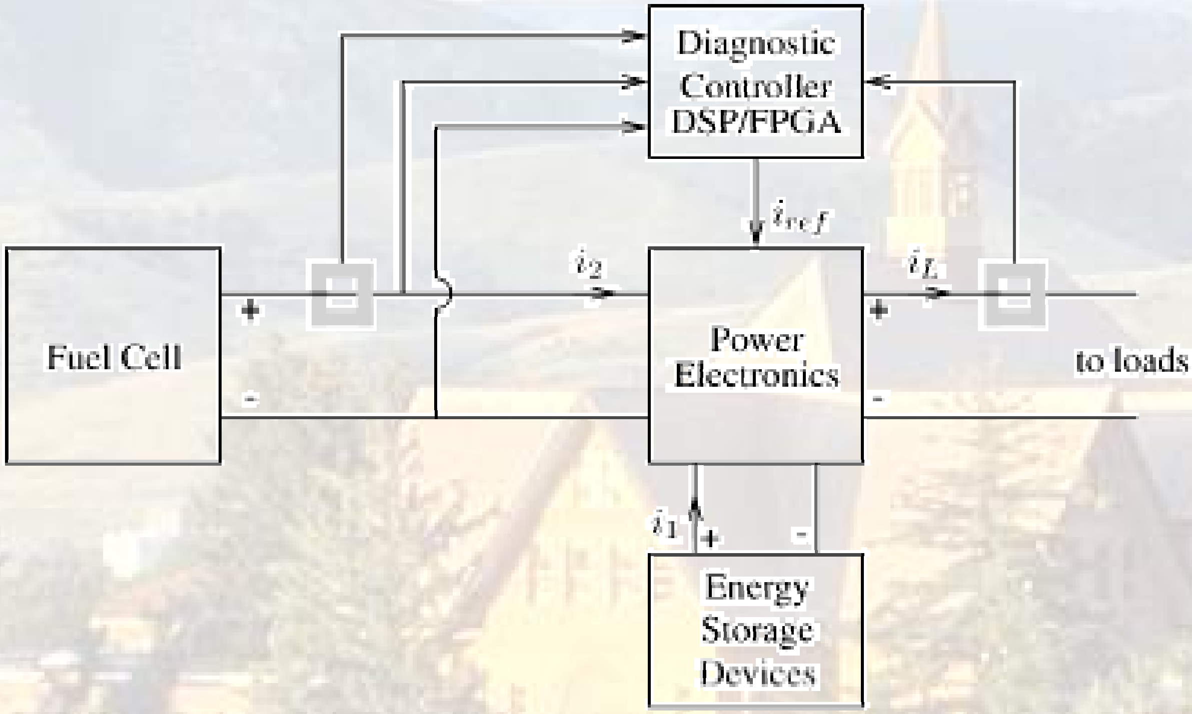


Predicted long-term load

Diagnostic Control Concepts

New Directions

Diagnostic-oriented controller



Continuously diagnose and adapt fuel cell response

Hydrogen Separation Membranes

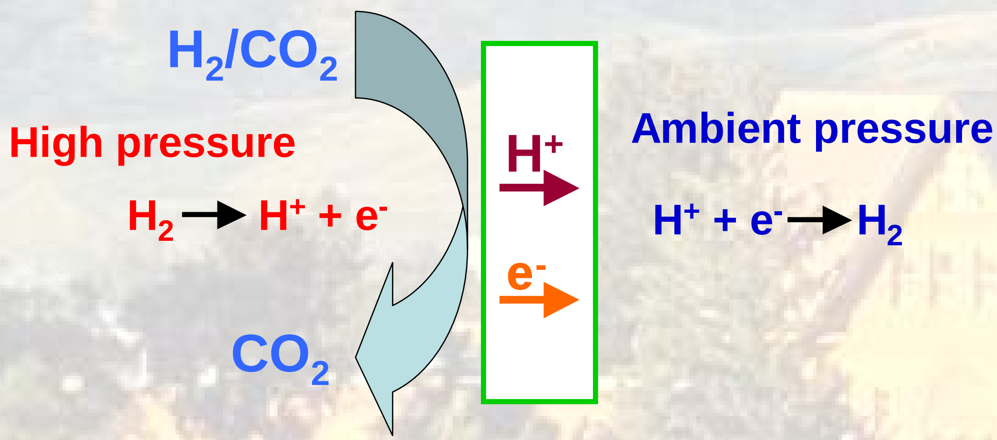
Coal $\xrightarrow{\text{gasification}}$ Syngas (H_2/CO) $\xrightarrow{\text{steam}}$ H_2/CO_2 $\rightarrow$ Hydrogen Separation Membrane $\rightarrow$ H_2

Hydrogen Separation Membrane $\downarrow$ CO_2

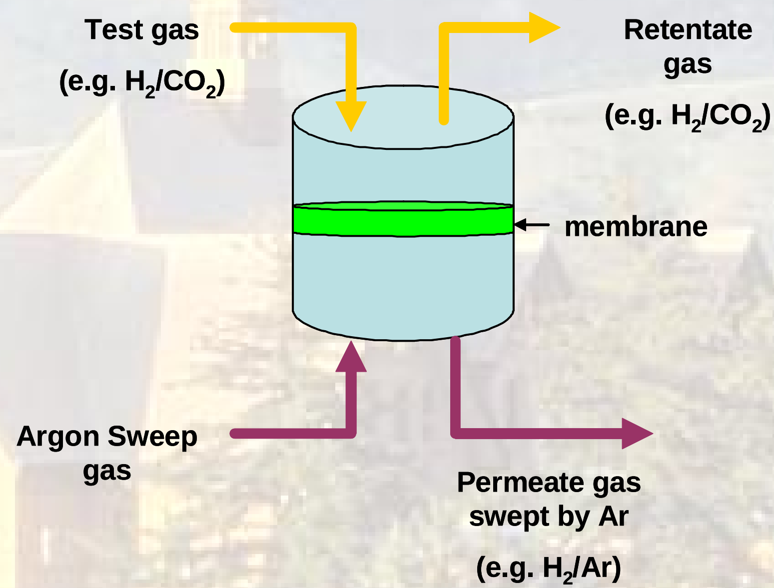
è Proton conducting oxides

H_2 from coal with simultaneous CO_2 sequestration (FutureGen project)

Mixed proton/electron transport membrane

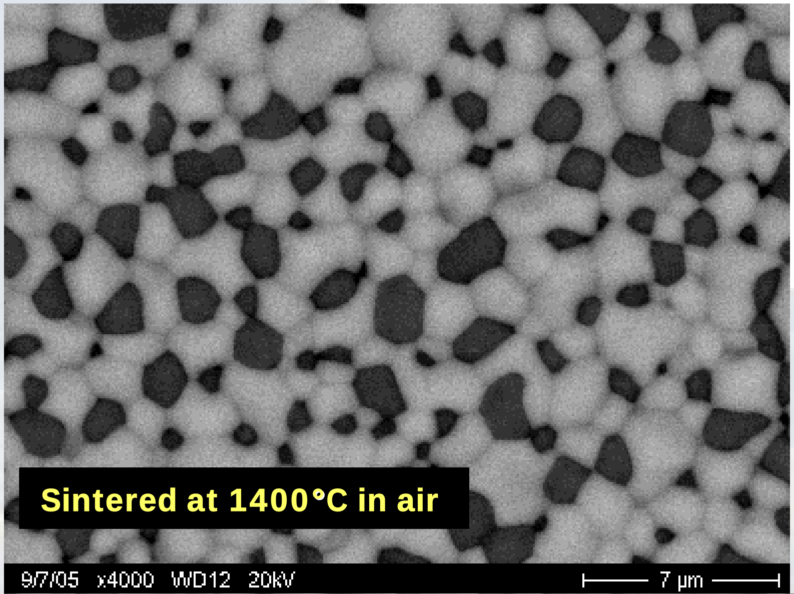


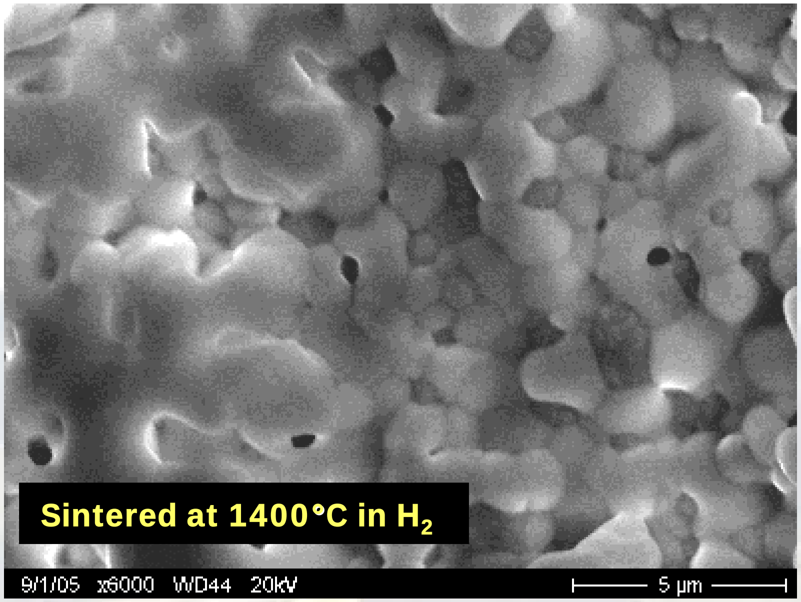
Principle of hydrogen separation

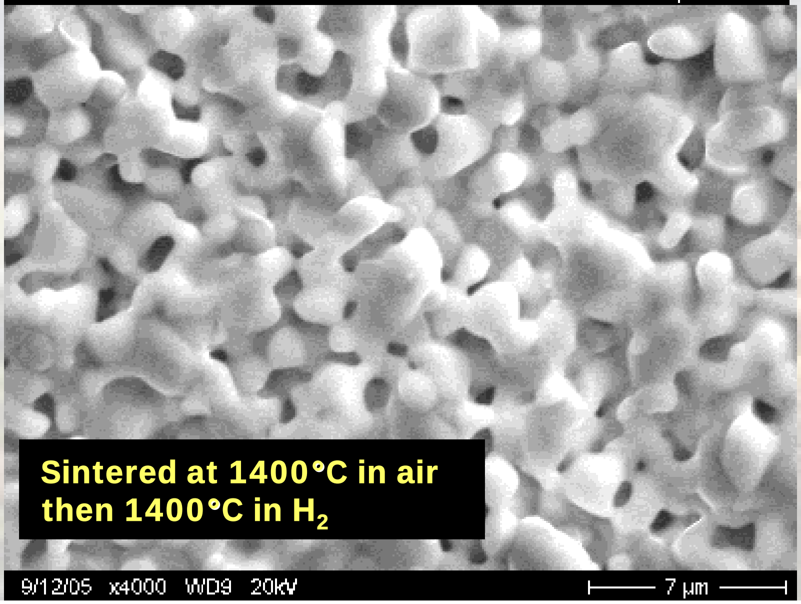


Proton Conducting Ceramics Test Chamber

Materials Synthesis







Synthesis of Novel Nickel-Barium Cerate Cermets

Characterize Processing Parameters and Performance

Other Areas of Activity

Gas Separation Technologies

- Currently solid oxide electrolysis membranes can be tailored selectively for proton and oxygen ion transport
- Novel membranes may yield new transport species and next generation gas separation technologies

Unitized Regerenative Solid Oxide Fuel Cells

- Long endurance UAV's, remote opertion

Bio fuels

- Fuel production from oilseed crops
- Focus on hydrogen production & impurity control

MSU-Bozeman Personnel

HiTEC and Other Fuel Cell Programs

Steve Shaw (EE)
Dick Smith (Physics)
Hashem Nehrir (EE)
Rahul Amin (ME)

Max Diebert (Chem Eng.)
Stephen Sofie (ME. Eng.)
Hugo Schmidt (Physics)
Joe Seymour (Chem E)

Hongwei Gao (EE)
Yves Idzerda (Physics)
Lee Spangler (Chem)
Sara Codd (ME)

+ 4 Postdoctorals, 15 Graduate Students, 15 Undergraduates
= 46 People working in this HiTEC program